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**EVALUATION OF ALUMINUM-COATED WIRES
AS REINFORCEMENT FOR ARTICULATED
CONCRETE MATTRESSES**

**SUPPLEMENTARY COMPARATIVE TESTS OF STAINLESS
AND COPPER-CLAD STEEL WIRES**



TECHNICAL REPORT NO 6-613

Report 2

May 1964

Conducted for

The President, Mississippi River Commission

by

**Lower Mississippi Valley Division
Materials and Concrete Laboratory**

**U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi**

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28

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ARMY-MRC VICKSBURG, MISS.

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PREFACE

The investigation reported herein was authorized by the President, Mississippi River Commission, in Comment No. 4, dated 26 September 1962, subject, "Evaluation of Proposed Reinforcement for Articulated Concrete Mattress." The investigation was a result of a review of the results of the basic program submitted to the President, Mississippi River Commission, by the Director, U. S. Army Engineer Waterways Experiment Station, in Comment No. 1, dated 5 July 1962, subject as above, in which it was stated that supplementary tests not previously authorized would be necessary.

The work was conducted at the Concrete Division, Waterways Experiment Station, by personnel of the Chemistry and Physical Tests Sections, under the supervision of Messrs. Thomas B. Kennedy, Bryant Mather, James M. Polatty, Rembert L. Curry, and Leonard Pepper. This report was prepared by Mr. Pepper.

Col. Alex G. Sutton, Jr., CE, was Director of the Waterways Experiment Station during the conduct of this work and the preparation and publication of this report; Mr. J. B. Tiffany was Technical Director.

CONTENTS

	<u>Page</u>
PREFACE	iii
SUMMARY	vii
PART I: INTRODUCTION	1
Background	1
Need for and Purpose of This Study	2
PART II: TESTING FOR GALVANIC EFFECT	3
Materials and Procedures	3
Results	4
PART III: TESTING FOR EFFECT OF PINHOLES ON TENSILE STRENGTH	8
Materials and Procedures	8
Results	9
PART IV: SUMMARY OF RESULTS AND CONCLUSIONS	12
Summary of Results	12
Conclusions	13
TABLES 1-5	
PHOTOGRAPHS 1-4	
PLATE 1	

SUMMARY

This study, supplementary to that reported in Report 1, was conducted to determine the galvanic effect between stainless steel and copper-clad wires and the effect on tensile strength of copper-clad wire of various diameter pinholes and the corrosion in the pinhole.

In the tests for galvanic effect, 4-in.-long specimens of stainless steel and copperweld wires were tied together with nylon thread. Ninety such couples were exposed, under one of three exposure conditions, to either 5000 ppm NaCl (pH 7) or dilute H_2SO_4 buffered at pH 5. Both solutions were maintained at 100 F and were changed at least every seven days. The couples were exposed completely immersed in the test solution, partially immersed in the test solution, or alternately completely immersed in the test solution for 1 hr and then dried in 100 F air for 1 hr. The degree of corrosion was determined, by visual observation and determination of the change in weight of the specimens, after 30, 90, 150, 210, and 270 days. It was found that:

- a. The galvanic effect of stainless steel on copperweld wire was a reduction in corrosion penetration in the copperweld from that normally obtained on copperweld alone for the storage conditions of complete or partial immersion in either solution. When the couples were alternately immersed (in either solution) and dried, the galvanic effect resulted in an increase in the corrosion penetration of the copperweld.
- b. The galvanic effect of copperweld on stainless steel wire was very slight. Essentially no galvanic effect was noted when the couples were stored in pH 5 solution. A slight reduction in corrosion penetration was noted when the couples were stored in salt solution. However, the magnitude of corrosion penetration in the stainless steel wire was so small that any change noted may have been due to testing errors.

In the tests for the effect of the pinhole on the tensile strength of the copperweld wire, a 0.020-in.-deep pinhole was drilled 7 in. from one end of each test specimen. Three pinhole diameters were evaluated: 0.006, 0.009, and 0.021 in. Forty-eight specimens (at least 16 in. long) were drilled for each diameter of pinhole. In addition, 39 extra 16-in. specimens were cut to be used to establish reference strengths for wire without pinholes and not exposed to a corrosive atmosphere. The specimens with the

pinhole were exposed, partially immersed or alternately partially immersed and dried in 100 F air, to either 5000 ppm NaCl (pH 7) or dilute H_2SO_4 buffered at pH 5. Again, both solutions were maintained at 100 F and changed at least every seven days. The tensile strengths of three specimens for each diameter pinhole were determined in accordance with ASTM Test Method A-318 after exposures of 0, 1, 3, and 6 months to each of the solutions and each of the storage conditions. The tensile strengths of the reference specimens were also determined at the same four ages. Results showed that:

- a. There was a linear correlation between reduction in tensile strength and the duration of partial immersion in either solution for copperweld wires with 0.021- or 0.009-in. pinholes.
- b. There was no significant change in tensile strength for the wires which were alternately immersed in either solution, nor for the wires with a 0.006-in. pinhole.

EVALUATION OF ALUMINUM-COATED WIRES AS REINFORCEMENT
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SUPPLEMENTARY COMPARATIVE TESTS OF STAINLESS
AND COPPER-CLAD STEEL WIRES

PART I: INTRODUCTION

Background

1. Articulated, reinforced concrete mattresses are used by the U. S. Army Corps of Engineers to stabilize much of the banks of the Mississippi River between New Orleans, La., and Cairo, Ill. The life of the mattress has been found to depend upon the corrosion resistance of the reinforcing fabric. A prior laboratory study, the basic program* to which the tests reported herein were supplementary, was conducted to evaluate the possible use of aluminum-clad wires (alumoweld) as a corrosion-resistant reinforcement for these mattresses as compared with the copper-clad wires (copperweld and copperply) that are presently being used. In that study, the corrosion rates of alumoweld, copperweld, copperply, spring steel, and stainless steel wires were determined for conditions of complete, partial, and alternate immersion of the wires in salt and pH 5 solutions, in mortar, and in an alkaline medium. The galvanic effect on the corrosion rate was determined by tying the alumoweld wire to each of the two different types of copper-clad wire, the alumoweld wire to the spring steel wire, and each of the two different types of copper-clad wire to the spring steel wire, and subjecting the resulting couples to the various types of immersion in the salt and pH 5 solutions. The effect of a 0.021-in.-diameter pinhole, drilled into the copper-clad and aluminum-clad wires, on the corrosion rates was also determined.

2. Results of the study indicated that:

- a. The aluminum-clad wires are readily and severely attacked by alkaline media such as are normally found both in concrete

* U. S. Army Engineer Waterways Experiment Station, CE, Evaluation of Aluminum-Coated Wires as Reinforcement for Articulated Concrete Mattresses: Basic Program. Technical Report No. 6-613, Report 1 (Vicksburg, Miss., December 1962).

and in the Mississippi River, whereas copper-clad and steel wires are not.

- b. The resistance of the aluminum-clad wires to corrosion in either salt or slightly acid solutions was much better than that of the spring steel but was not equal to that of the copper-clad or the stainless steel wires.
- c. The galvanic effect resulted in an increase in the rate of corrosion of the aluminum and a decrease in that of copper when the aluminum- and copper-clad wires were coupled with each other. The galvanic effect resulted in an increase in the rate of corrosion of the spring steel when it was coupled with copper and a decrease when it was coupled with aluminum.
- d. A 0.021-in.-diameter pinhole in clad wires is large enough to cause a galvanic effect between the coating and the core metal.

It was therefore recommended that aluminum-clad wires not be used as reinforcement for articulated concrete mattresses.

Need for and Purpose of This Study

3. On reviewing the results of the basic program, the Mississippi River Commission noted that the program had not determined the galvanic effect of coupling stainless steel and copper-clad wires. Both kinds of wire are used for the mattress fabric and connectors, and at times these dissimilar metals are tied together. Thus it was judged advantageous to know the galvanic effect, if any, between them. In addition, the Commission noted that no observations of the pinholes were made to determine the extent of corrosion penetration into the core metal and the effect of the corrosion in the pinhole on the tensile strength of the wire.

4. Therefore, the Commission authorized the additional tests reported herein to determine:

- a. The galvanic effect between stainless steel and copper-clad wires.
- b. The effect on the tensile strength of copper-clad wire of various diameter pinholes and also of corrosion in the pinholes.

PART II: TESTING FOR GALVANIC EFFECT

Materials and Procedures

Materials

5. Portions of the coils of wire obtained for the basic program were still available for use in this supplementary study. Since similar results were obtained with both types of copper-clad wire in the basic program, only the copperweld wire was used in this study. The types of wire used were:

<u>Symbol</u>	<u>Type of Wire</u>
MRC-2 Cu-1	Copperweld
MRC-2 SS-1	18/8 stainless steel, type 302

Specimen preparation

6. Specimens, each 4 in. long, were cut from both ends and the middle of each coil of wire. Then the specimens were mixed to prevent segregation in accordance with coil position, and cleaned. After cleaning, the specimen weight and length were recorded. The copperweld specimens were examined to ascertain that the copper coating was free of defect. A numbered adhesive tape was affixed to one end of each specimen for identification. Both ends of each specimen were protected with an epoxy-resin coating which covered approximately 1/4 in. of the specimen length at one end of the wire (completely covering the identification tape) and approximately 1/8 in. at the other end. After the resin coating had hardened, the specimen weight and the length of bare wire were recorded. Then each stainless steel specimen was tied to a copperweld specimen with nylon thread; a total of 90 such couples were made.

Test solutions and exposure conditions

7. The couples were exposed, under one of three exposure conditions, to either 5000 ppm NaCl (pH 7) or dilute H_2SO_4 buffered at pH 5. Both solutions were maintained at 100 F and were changed at least every seven days. Fifteen couples were stored in each of six 2-liter plastic containers; one container was used for each solution and exposure condition. The couples were exposed:

- a. Completely immersed in the test solution.
- b. Partially immersed, i.e. suspended vertically with 2-1/2 to 3 in. of the couple immersed in the test solution.
- c. Alternately completely immersed in the test solution for 1 hr and then dried in 100 F air for 1 hr.

Method of determining degree of corrosion

8. The degree of corrosion was determined, by visual observation and determination of the change in weight of the specimens, after 30, 90, 150, 210, and 270 days. Before the corroded specimens were weighed, the wires were first carefully wire-brushed and then chemically cleaned, using the following cleaning solutions:

<u>Wire</u>	<u>Solution</u>	<u>Immersion Time, min</u>
Copperweld	5% nitric and 2-1/2% oxalic acids	5
Stainless steel	1:10 sulfuric acid	2

At later ages it was often necessary, even after chemical cleaning, to rub the specimens lightly with very fine steel wool to remove all the corrosion. After cleaning, all specimens were weighed to the nearest 0.1 mg. Specimens that had been exposed to the effects of a corrosive medium for a specified time and then removed, cleaned, and weighed were not reexposed for additional periods of time. Data on effects of longer exposure were obtained by use of additional specimens continuously exposed for the specified times.

Results

Expression of results

9. The degree of corrosion of the coupled specimens was determined as a weight loss in milligrams per 10-cm length of specimen. In order to compare the corrosion rates of dissimilar metals, the degree of corrosion is shown in this report as an average corrosion penetration (average of three specimens) in 10^{-4} cm. The corrosion penetration was calculated from the weight-loss data by assuming the densities of stainless steel and copper to be 7.81 and 8.92 g/cc, respectively.

Galvanic effect on copperweld wire

10. The corrosion of the copperweld wire coupled with stainless steel wire was similar to that reported for copper-clad wires in Report 1 in that it was uniformly distributed over the entire length of the exposed specimen except for the storage condition in which the couples were partially immersed in either pH 5 or NaCl solution. When the couples were partially immersed in either corrosive solution, the corrosion of the copperweld wire was concentrated on that part of the specimen above the solution level.

11. The average corrosion penetrations in the copperweld wire when that wire was coupled with the stainless steel wire are shown in table 1. For purposes of comparison, table 1 also shows the normal copperweld corrosion penetration (i.e. the corrosion that occurs in copperweld wire that is not coupled with a dissimilar metal) and the corrosion penetration in copperweld wire coupled with spring steel and alumoweld wires. These additional data were interpolated from the results reported in Report 1.

12. As can be seen in table 1, the galvanic effect of stainless steel on copperweld wire was a reduction in corrosion penetration in the copperweld from that normally obtained on copperweld alone for the storage conditions of complete or partial immersion in either solution. For these storage conditions the galvanic effect was greatest for spring steel and least for stainless steel. When the couples were alternately immersed (in either solution) and dried, the galvanic effect of stainless steel was an increase in the corrosion penetration in the copperweld over that normally obtained on copperweld alone. The galvanic effect of spring steel for this condition was approximately equal to the effect produced by stainless steel, whereas the effect of alumoweld was to reduce the corrosion penetration. The following corrosion penetration rates were estimated by extrapolation of the data given in table 1:

Storage Condition	Copperweld Corrosion Penetration Rate, in 10^{-4} cm/yr			
	Copperweld Alone	Copperweld Coupled with		
		Stainless Steel	Alumo- weld	Spring Steel
Partial immersion in NaCl solution	154	89	89	9
Complete immersion in NaCl solution	50	34	16	1

(Continued)

Storage Condition	Copperweld Corrosion Penetration Rate, in 10^{-4} cm/yr			
	Copperweld Alone	Copperweld Coupled with		
		Stainless Steel	Alumo- weld	Spring Steel
Alternate immersion in NaCl solution	15	29	11	24
Partial immersion in pH 5 solution	81	38	23	4
Complete immersion in pH 5 solution	50	32	20	5
Alternate immersion in pH 5 solution	15	22	6	18

Galvanic effect on stainless steel

13. Very little corrosion was observed on the stainless steel wires. Slight pitting, uniformly distributed over the length of the specimen, was observed at later ages for those couples that were alternately immersed in the salt solution and dried. Specimens that were partially immersed in the salt solution were observed to be slightly pitted above the solution level at later ages.

14. The average corrosion penetrations in the stainless steel when that wire was coupled with copperweld wire are shown in table 2 along with the normal corrosion penetration in stainless steel. The latter data were interpolated from the data previously reported for stainless steel in Report 1. It is evident in table 2 that the galvanic effect of copperweld on stainless steel is very slight. Essentially no galvanic effect was noted when the couples were stored in pH 5 solution. A reduction in corrosion penetration was noted when the couples were stored in salt solution. The following corrosion penetration rates were estimated by extrapolation of the data given in table 2:

Storage Condition	Stainless Steel Corrosion Penetration Rate, in 10^{-4} cm/yr	
	Stainless Steel	Stainless Steel Coupled with Copperweld
Partial immersion in NaCl solution	7	3
Complete immersion in NaCl solution	5	3
Alternate immersion in NaCl solution	7	6
Partial immersion in pH 5 solution	4	4
Complete immersion in pH 5 solution	2	2
Alternate immersion in pH 5 solution	3	3

Testing error and efficiency

15. The error of the tests of galvanic effect made in this

investigation was of the same order of magnitude as that in the basic program (i.e. 8 to 10 percent), particularly at later test ages. Epoxy resin did not adequately protect the ends of the specimen, although the resin provided a better cover than the paraffin previously used. The test ages used in this investigation proved to be more efficient and economical than the test ages previously used for the determination of the rate of corrosion penetration.

PART III: TESTING FOR EFFECT OF PINHOLES
ON TENSILE STRENGTH

Materials and Procedures

Specimen preparation

16. Specimens, at least 16 in. long, were cut from both ends and the middle of the coil of copperweld wire. Then the specimens were mixed to prevent segregation in accordance with coil position, and examined to ascertain that the copper coating was free of defects. In each specimen, one 0.020-in.-deep pinhole was drilled, 7 in. from one end. Three pinhole diameters were evaluated: 0.006, 0.009, and 0.021 in. Forty-eight specimens were drilled for each diameter of pinhole. In addition, 39 extra 16-in. specimens were cut to be used to establish reference strengths for wire without pinholes and not exposed to a corrosive atmosphere. All 183 specimens were cleaned, and a numbered adhesive tape was affixed to the end farthest from the pinhole for identification. Both ends of each specimen were protected with an epoxy-resin coating which completely covered the identification tape.

Test solutions and
exposure conditions

17. The specimens with the pinhole were exposed, to either 5000 ppm NaCl (pH 7) or to dilute H_2SO_4 buffered at pH 5, as follows:

- a. Partially immersed, i.e. suspended vertically with 7 in. of the specimen (the end with the pinhole) immersed in the test solution.
- b. Alternately partially immersed in the test solution for 1 hr and then dried in 100 F air for 1 hr.

Both solutions were maintained at 100 F and changed at least every seven days. Nine specimens of the same pinhole diameter were stored in separate 5-liter plastic containers for each solution and exposure condition.

Method of determining the tensile strength

18. The tensile strengths of three specimens for each diameter

pinhole were determined in accordance with ASTM Test Method A-318* after exposures of 0, 1, 3, and 6 months to each of the solutions and each of the storage conditions. The tensile strengths of the reference specimens were also determined at the same four ages. Photomicrographs were taken at and across the pinholes of several specimens in which the break occurred at or near the pinhole (see photographs 1-4).

Results

Reference specimens

19. At least three reference specimens were tested in tension on the same day on which test specimens (i.e. the specimens with pinholes that had been exposed to the corrosive solutions) were tested in tension. The average breaking loads of the reference specimens are given in table 3. The random error (within-group standard deviation) for the reference specimen tensile test was found to be homogeneous and equal to 47.4 lb with 27 degrees of freedom. The averages were all found to be statistically equal except for that obtained at the time the tensile tests were conducted on test specimens having pinhole diameters of 0.021 or 0.009 in. and partially immersed for 6 months in either corrosive solution. The resultant grand average tensile breaking load for the reference specimens was 4595 lb.

Test specimens

20. The average breaking loads for the test specimens are given in table 4. Only the test results obtained for specimens having pinhole diameters of 0.021 and 0.009 in. and partially immersed for 1, 3, and 6 months in either solution are significantly different, at the 95 percent confidence level, from the average tensile breaking load obtained for the reference specimens. Therefore, regression analyses were conducted for these four conditions, including all four ages. The following results were obtained:

* American Society for Testing Materials, "Materials test methods" (except "Chemical analysis"), 1958 Book of ASTM Standards, Part 3 (Philadelphia, Pa., 1958).

Pinhole Diameter in.	Partial Immersion in	Regression Equation	Correlation Coefficient
0.021	NaCl	$Y = 4536 - 300x$	-0.985 ± 0.514
0.021	pH 5	$Y = 4457 - 125x$	-0.877 ± 0.514
0.009	NaCl	$Y = 4517 - 96x$	-0.938 ± 0.514
0.009	pH 5	$Y = 4532 - 26x$	-0.675 ± 0.514

The slope of each equation is significantly different from zero. The data and the least square lines are shown in plate 1. Photomicrographs representing the above four conditions are shown in photographs 1-4.

21. The significant reduction in tensile strength noted above is due to the corrosion in the pinholes reducing the effective diameter of the specimen. The rate of reduction in strength, which is a function of the rate of reduction of the effective diameter of the specimen, is equal to the slope of the above-listed regression equations. It is obvious that the slope is larger for the larger pinhole diameter, and also that the slope is greater for immersion in NaCl solution than for immersion in pH 5 solution. However, the correlation between pinhole diameter and corrosive solution cannot be effectively determined with the limited data available from this study.

22. The average tensile strength of the test specimens tested under eight different conditions was not significantly different from the average tensile strength of the reference specimens. However, prolonged exposure, for one or more years, may reduce the tensile strength of test specimens subjected to several of the above conditions so that the average tensile strength of the test specimens would be significantly different from the strength of the reference specimens.

23. The location of the tensile break was observed, particularly with regard to the number of wires in each group of three specimens that broke at the pinhole. These data are given in table 5. Breaks at the pinhole may have been fortuitous; however, the number of breaks at the pinhole, for each group, suggests that the pinhole area is the weakest part of the wire. The data in table 5 suggest that prolonged exposure to the corrosive solution may significantly reduce the tensile strength of wires tested under the following conditions:

<u>Pinhole Diameter in.</u>	<u>Storage Condition</u>	<u>Corrosive Solution</u>
0.006	Partial immersion	NaCl
0.021	Alternate immersion	pH 5
0.021	Alternate immersion	NaCl
0.009	Alternate immersion	pH 5

Testing error

24. The testing error in the determination of the tensile strength of the reference specimens was found to be equal to 47.4 lb, approximately nine times greater than the error of reading the dial of the testing machine. The testing error in the determination of tensile strength of the test specimens which were found to have the same tensile strength as the reference specimens was also equal to 47 lb. The ninefold increase in the testing error was probably due to:

- a. The variation in the diameter of the wires.
- b. The method of gripping the wires for the test.
- c. The curvature of the wire.

The testing error in the determination of tensile strength of the test specimens which were found to have a significantly lower tensile strength than the reference specimens was approximately 150 lb. The threefold increase in error was entirely due to the corrosion within the pinhole.

PART IV: SUMMARY OF RESULTS AND CONCLUSIONS

Summary of ResultsGalvanic effect

25. Copperweld wire. Coupling stainless steel with copperweld wire reduced the corrosion penetration in the copperweld wire for the test conditions in which the couples were either partially or completely immersed in either solution. The reduction in corrosion penetration was not as great as that obtained by coupling spring steel with copperweld wire. However, the stainless steel-copperweld couple increased the corrosion penetration in the copperweld for the test condition in which the couple was alternately immersed in either solution. The increase in corrosion penetration was of the same magnitude as that attained by coupling spring steel with the copperweld wire. The increased corrosion penetration in the copperweld wire for this latter condition was less than the reduced corrosion penetration produced when the stainless steel-copperweld couple was completely immersed in either solution.

26. Stainless steel wire. The effect of coupling copperweld to stainless steel wire was to reduce the corrosion penetration in the stainless steel wire for all storage conditions in NaCl solution. No change in corrosion penetration of the stainless steel wire occurred when the couple was stored in pH 5 solution. However, the magnitude of the corrosion penetration in the stainless steel wire was so small that the changes that were noted may be insignificant because of testing error.

Effect of pinhole diameter and corrosion on tensile strength

27. The corrosion in the 0.021- and 0.009-in. pinholes in the copperweld wire, produced by partial immersion in either solution, reduced the tensile strength of the wire. The reduction in strength was linear with the duration of immersion in the solution. The following rates of tensile strength reduction were determined:

<u>Pinhole Diameter, in.</u>	<u>Partial Immersion in</u>	<u>Rate of Tensile Strength Reduction, lb/month</u>
0.021	NaCl	300
0.021	pH 5	125

(Continued)

<u>Pinhole Diameter, in.</u>	<u>Partial Immersion in</u>	<u>Rate of Tensile Strength Reduction, lb/month</u>
0.009	NaCl	96
0.009	pH 5	26

Significant tensile strength reductions were not found for specimens with a 0.006-in. pinhole for any of the test conditions, nor for specimens having pinholes of 0.021 and 0.009 in. when the specimens were alternately immersed in either solution.

Conclusions

28. A compilation of the available water analyses of the Mississippi River within the boundaries of the Lower Mississippi Valley Division was made in Report 1. The river water was found to vary with time and place of sampling. In general, the water was alkaline and contained a low concentration of chloride ion. Therefore, the reduction in tensile strength and the corrosion penetration in the copperweld wire, determined both in this study and that reported in Report 1, would not normally be expected to occur at all points along the river. However, corrosive conditions may occur in a few isolated areas along the banks of the river, and such conditions can be detected prior to placement of the concrete mattresses. It should be noted that pinhole diameters smaller than 0.003 in. can be readily detected by means of the ferroxyl test.

Table 1

Average Galvanic Effect on Corrosion Rate of Copperweld of
Storage in NaCl and pH 5 Solutions for 30 to 270 Days

Wire	Average Corrosion Penetration, in 10^{-4} cm									
	5000 ppm NaCl					pH 5				
	30 days	90 days	150 days	210 days	270 days	30 days	90 days	150 days	210 days	270 days
<u>Complete Immersion</u>										
Copperweld coupled with										
Stainless steel	2	6	13	19	29	1	5	11	18	28
Spring steel	0	1	1	1	1	0	1	2	3	4
Alumoweld	1	4	6	9	11	1	4	8	11	14
Copperweld	4	12	21	29	37	4	12	21	29	37
<u>Partial Immersion</u>										
Copperweld coupled with										
Stainless steel	4	18	32	41	45	2	7	8	21	39
Spring steel	1	2	3	5	6	1	1	2	3	3
Alumoweld	2	16	31	45	60	2	6	9	13	17
Copperweld	12	37	63	89	114	6	19	33	46	59
<u>Alternate Immersion and Drying</u>										
Copperweld coupled with										
Stainless steel	2	8	14	17	17	1	4	10	12	15
Spring steel	2	6	10	14	18	2	4	7	10	13
Alumoweld	0	2	4	6	7	1	2	2	3	4
Copperweld	3	5	7	9	11	3	5	7	9	11

Note: The data on the corrosion of copperweld alone and copperweld coupled with spring steel and alumoweld were interpolated from the data in Report 1.

Table 2

Average Galvanic Effect on Corrosion Rate of Stainless Steel
of Storage in NaCl and pH 5 Solutions for 30 to 270 Days

Wire	Average Corrosion Penetration, in 10^{-4} cm									
	5000 ppm NaCl					pH 5				
	30 days	90 days	150 days	210 days	270 days	30 days	90 days	150 days	210 days	270 days
<u>Complete Immersion</u>										
Stainless steel coupled with Copperweld	1	1	2	2	2	1	1	2	2	3
Stainless steel	2	3	3	3	4	2	2	3	3	3
<u>Partial Immersion</u>										
Stainless steel coupled with Copperweld	3	1	1	1	2	1	1	1	2	3
Stainless steel	3	4	5	6	7	1	1	2	2	2
<u>Alternate Immersion and Drying</u>										
Stainless steel coupled with Copperweld	2	1	2	4	6	1	1	1	2	2
Stainless steel	2	3	4	5	6	1	1	2	2	2

Note: The data on the corrosion of stainless steel alone were interpolated from the data in Report 1.

Table 3

Average Tensile Breaking Loads of Reference Specimens* of Copperweld

<u>Tested with Test Specimens Having</u>		<u>Average Tensile Breaking Load of</u>			
<u>Pinhole</u> <u>Diameter</u> <u>in.</u>	<u>Exposure Condition</u>	<u>Reference Specimens, lb</u>			
		<u>0</u> <u>month</u>	<u>1</u> <u>month</u>	<u>3</u> <u>months</u>	<u>6</u> <u>months</u>
0.021 0.009	Partial immersion in NaCl and in pH 5	4570	4610	4557	4473
0.021 0.009	Alternate immersion in NaCl and in pH 5	4623	4610	4557	4653
0.006	Partial and alternate immersion in NaCl and in pH 5	4543**	4633	4607	4637

* Pinholes were not drilled in the reference specimens, nor were the reference specimens exposed to the corrosive liquids. The pinhole diameters, storage conditions, and ages given in this table refer to the test specimens that were broken at the time the reference specimens were broken.

** Average of six reference specimens. The other data represent average of three reference specimens.

Table 4

Effect of Pinhole Diameter and Corrosion on
Tensile Strength of Copperweld Wire

Pinhole Diameter in.	Reference Specimens	Average Tensile Breaking Load, lb					
		After Exposure to 5000 ppm NaCl for			After Exposure to pH 5 for		
		1	3	6	1	3	6
		<u>month</u>	<u>months</u>	<u>months</u>	<u>month</u>	<u>months</u>	<u>months</u>
<u>Partial Immersion</u>							
0.021	4507*	4287	3667	2710	4213	4080	3727
0.009	4538*	4390	4197	3963	4483	4467	4373
0.006	4602**	4583	4557	4577	4563	4587	4623
<u>Alternate Immersion and Drying</u>							
0.021	4590*	4520	4527	4597	4540	4530	4573
0.009	4583*	4570	4580	4617	4560	4560	4520
0.006	--	4570	4593	4570	4560	4590	4597

Note: All values represent an average of three specimens except as follows:

- * Average of six specimens.
- ** Average of twelve specimens.

Table 5

Effect of Pinhole Diameter and Corrosion on Location
of Tensile Break of Copperweld Wire

Pinhole Diameter in.	Reference Specimens	Number of Breaks Located at Pinhole					
		After Exposure to 5000 ppm NaCl for			After Exposure to pH 5 for		
		1	3	6	1	3	6
		<u>month</u>	<u>months</u>	<u>months</u>	<u>month</u>	<u>months</u>	<u>months</u>
<u>Partial Immersion</u>							
0.021	0*	3	3	3	3	3	3
0.009	0*	2	3	2	3	3	3
0.006	0**	1	2	2	0	2	0
<u>Alternate Immersion and Drying</u>							
0.021	0*	3	1	1	1	3	3
0.009	0*	0	0	1	0	1	2
0.006	--	0	0	0	0	1	0

Note: Maximum number of breaks to be expected at the pinhole for any group is three, except as follows:

* Maximum number of breaks to be expected at the pinhole for this group is six.

** Maximum number of breaks to be expected at the pinhole for this group is twelve.



6 3 1 0

Exposure, months

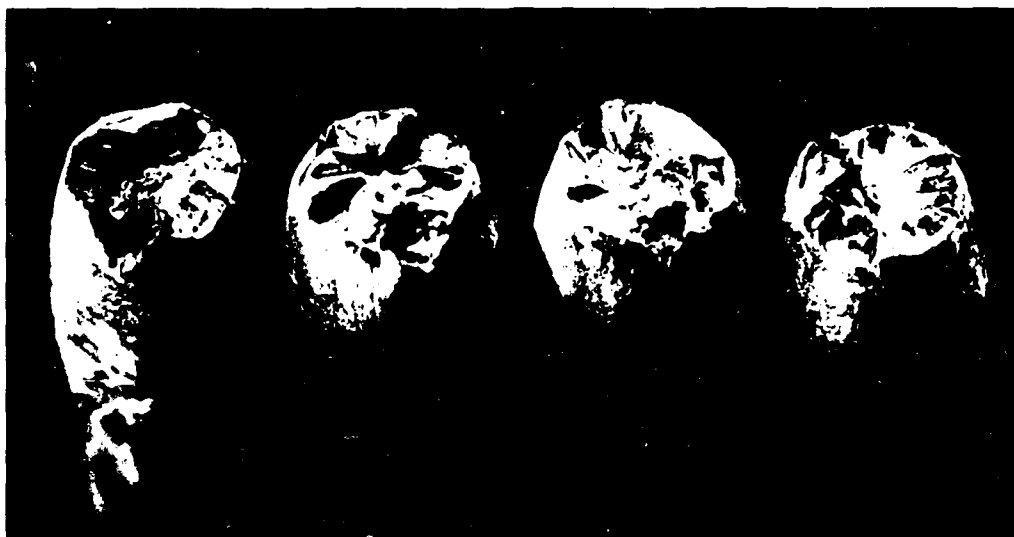
Photograph 1. Effect of partial immersion in NaCl solution on 0.021-in. pinhole in copperweld ($\times 8$)



6 3 1 0

Exposure, months

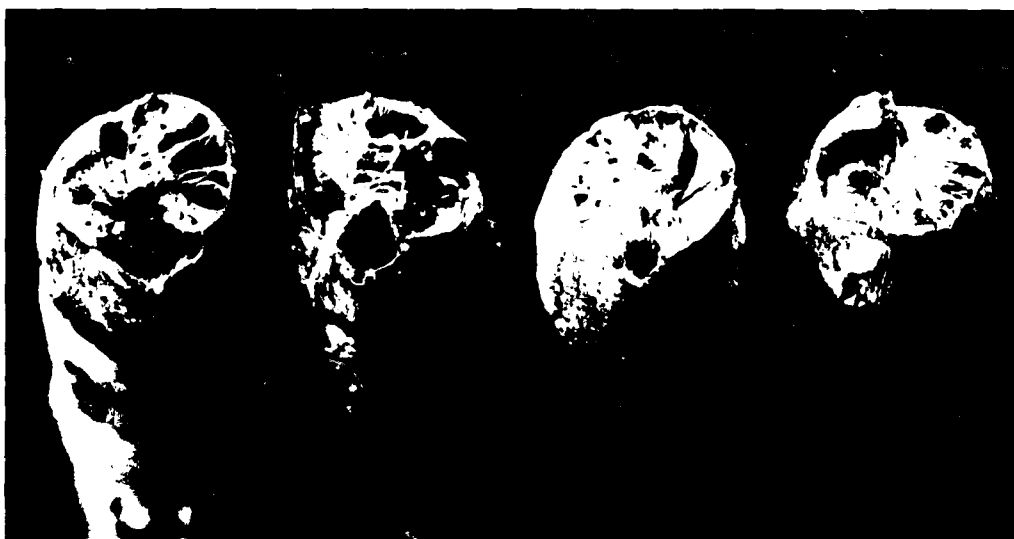
Photograph 2. Effect of partial immersion in pH 5 solution on 0.021-in. pinhole in copperweld ($\times 8$)



6 3 1 0

Exposure, months

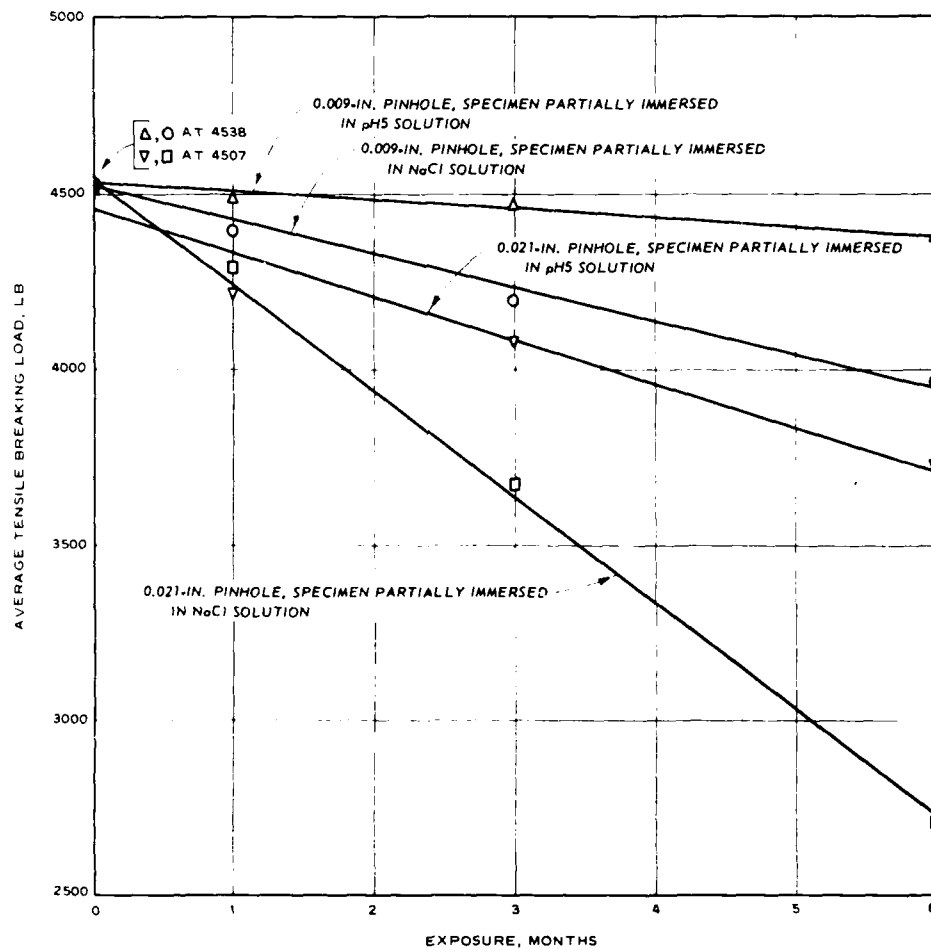
Photograph 3. Effect of partial immersion in NaCl solution on 0.009-in. pinhole in copperweld ($\times 8$)



6 3 1 0

Exposure, months

Photograph 4. Effect of partial immersion in pH 5 solution on 0.009-in. pinhole in copperweld ($\times 8$)



EFFECT OF PINHOLE
DIAMETER AND CORROSION
ON TENSILE STRENGTH OF
COPPERWELD WIRE

